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Photographic and mechanical properties of nuclear research emulsions

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PHOTOGRAPHIC AND MECHANICAL PROPERTIES OF NUCLEAR RESEARCH EMULSIONS

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OF NUCLEAR RESEARCH EMULSIONS

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ABSTRACT

The effects of heating Ilford types G and K emulsion prior to exposure or processing have been studied. Samples were heated at 55-60°C for times up to 16 days, and other samples were assembled into stacks in which a temperature gradient (-20° to +100°C) was maintained. It was found that sensitivity to fast electron tracks can be increased by heating and drying, but that for each emulsion type there is a rather critical temperature above which the growth of random "fog grain" background soon makes the emulsion useless. Attempts to remove the latent image showed that track images are removed more easily than the background, so that the usefulness of emulsions that have been heated too much cannot be regained. We noted an interesting difference in the behavior of pellicles and pre-mounted plates which suggests that the plates are less affected by high temperatures. Measurements of Brinell hardness and thermal conductivity as a function of the humidity are reported, as are several

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1. Introduction

The use of nuclear research emulsions as an instrument for detection and measurement of radiation has led to several questions regarding the behavior and properties of emulsion under varying conditions of temperature and humidity. Most of the previous work done on emulsion properties has been sporadic and generally incidental to their use for a specific task. Recent results reported by Romanovskaya, Bogomolov, and Deberdeev of the NIKFI Institute in Moscow, in which a sensitivity increase of 35% with an accompanying increase in fog background of 17% was claimed for dry preheated NIKFI emulsion which was then exposed to relativistic electrons, have focused our interest on the effects of drying and/or heating emulsion prior to exposure, with a view to enhancing its efficiency as a research tool. [1] In view of the NIKFI results and the need for similar data for other emulsion types, we have undertaken an investigation of some of the properties of Ilford types G.2, G.5, and K.5 nuclear research emulsions, manufactured by Ilford Ltd., London, England.

In order to investigate the functional dependence of "fog" background (by fog we mean the presence of random silver grains which do not constitute useful information in the developed emulsion) and of emulsion sensitivity to particles near the minimum of ionization, we have used two separate techniques:

(1) Emulsion samples, previously dried in a dessicator, were heated to 55°-60°C for times ranging from 0 to 16 days, then exposed to a Co^{60} source and processed.

(2) Emulsion samples, also previously dried, were assembled into stacks 3/4 inches wide and 6 inches long and then a uniform temperature

gradient ranging from -20°C to +100°C was maintained in the stacks for periods ranging from 1 to 24 hours, and in one sample, for 7 days. These stacks were also exposed to Co^{60} sources.

The pellicles from these experiments were compared with control pellicles which had neither been dried nor heated to determine the effect of this "conditioning" of the emulsion on fog and sensitivity. All emulsion samples of a particular type, including the control pellicles, were from the same manufacturer's batch, and as far as possible were cut from the same large sheet of emulsion.

Some variations in the developing process were introduced in order to see if fog could be inhibited without reducing the quality of near-nimimum tracks. These variations are discussed in Section 2.F..

Eradication of the latent image by warming the emulsions at high (~100%) relative humidity was also investigated, again to see if fog could be reduced without total destruction of track latent images. This investigation is discussed in Section 2.D.

It was concluded from the data which follow, that:

(1) Emulsion sensitivity is somewhat increased by drying and heating, but the increase in fog generally dominates, so that the conditioned emulsions are inferior to normal emulsions.

(2) Eradication removes the latent image of near-minimum tracks more readily than the latent image of fog grains, so is not useful in improving the quality of an exposed emulsion.

(3) Under-development does not improve the quality of the exposed emulsions - that is, the fog grains develop at least as rapidly as the track grains.

In addition to considering the photographic properties of emulsions, a number of observations of a practical nature were made concerning the

handling of dry emulsions, difficulties in mounting dried or eradicated emulsions, and the problems concerning the sticking of one pellicle to another when emulsions are heated.

Some measurements of the thermal conductivity of emulsions as a function of relative humidity are described in Section 2.H, as well as a correlation between relative humidity and emulsion hardness.

2. Experimental Arrangements

A. Drying Procedure

The pellicles were dried in an aluminum dessicator manufactured by Precision Scientific Company. The dessicant used was $CaSO_4$. It took about five days, depending on the thickness of the pellicles, to extract the moisture from the emulsions. This length of time was estimated from the observation that after 2 days of drying the pellicles were hard and brittle. This was an indication that most of the moisture had left the emulsions. Therefore, another 2 or 3 days in the dessicator gave assurance that the emulsions were dry. Also, measurements made at the Lawrence Radiation Laboratory on the drying of emulsions in vacuum indicate a similar time. [2,3]

B. Constant Temperature Methods

A constant temperature oven manufactured by the Central Scientific Company was used to heat previously dried emulsions for various times. The oven was well-insulated and light-tight with interior dimensions of 12 inches by 12 inches by $14\frac{1}{2}$ inches. A thermometer inserted into the oven from the top was used to monitor the oven temperature. This oven was very satisfactory in keeping the temperature constant at the desired values, with a maximum variation of ± 0.5°C from the desired setting being observed for the entire heating period. Relative humidity in the oven was measured with a commercial hygrometer manufactured by Airguide Instrument Company of Chicago and was found to be essentially zero after one day of heating at 55° or 60 °C. Since it was desired that the pellicles remain in a dry environment during heating, this very low relative humidity in the oven allowed heating of the pellicles with assurance that they would remain dry while in the oven without adding dessicant.

The pellicles were placed in the oven on Plexiglas trays at equal time intervals and removed simultaneously at the end of the heating period. This procedure allowed immediate processing, in the same developing solution, of pellicles which had been heated for different lengths of time. Emulsions were heated in this method for periods up to and including 16 days at 60 °C (stack 1) and up to 9 days at 55 °C (stacks 2 and 3). Results of these procedures are shown and discussed in section 3.A on fog background and sensitivity.

C. Temperature Gradient Method

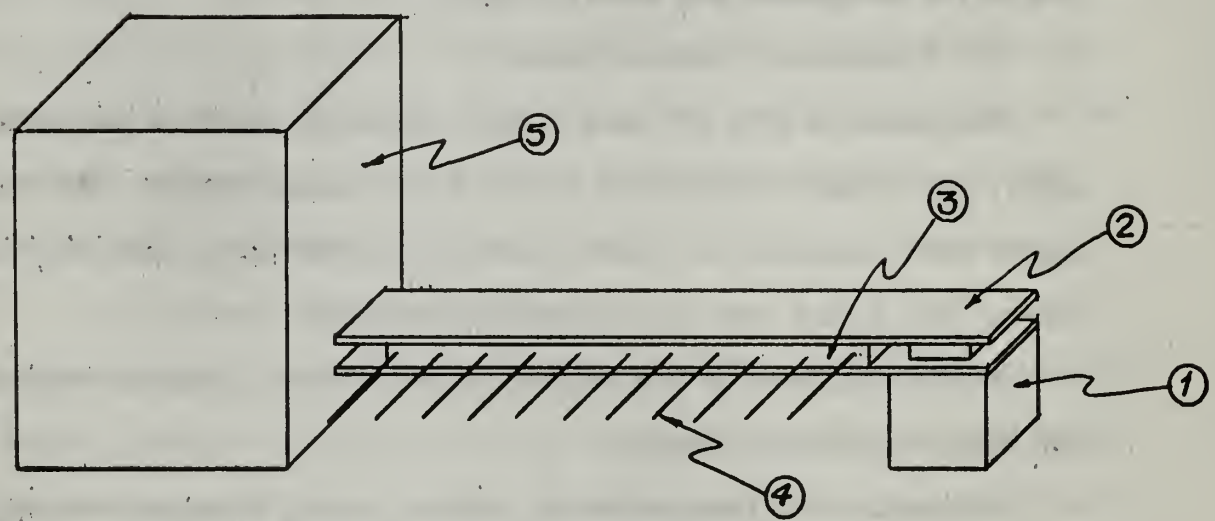
Emulsions in 6 by 3/4 inch strips, protected by black photographic paper, were placed between two 1 by 9 inch aluminum plates. The aluminum plates were connected to a heat source at one end and a heat sink at the other. The device used is illustrated in Fig. 1.

This arrangement gave a continuous temperature gradient between the two fixed temperature sources.

To measure the temperature at various points, 8 copper-constantan (#30-55-1) thermocouples were constructed and inserted between the central emulsion strips, and spaced from the hot to the cold end of the stack. By placing the thermocouples against the pellicle adjacent to the aluminum, and against the aluminum itself, it was determined that the isotherms were essentially perpendicular to the aluminum, so that the temperature at a point of any pellicle in a stack depended only on the distance from the hot (or cold) end of the pellicle. The thermocouples were connected to a revolving switch associated with a graphic recorder which recorded in sequence the reading from each thermocouple. Because room temperature was fairly constant, $72 \pm 2°F$, it was used as the known constant temperature "cold junction" for calibrating thermocouples.

Fig. 1.

Temperature Gradient Device



① Resistor — heat source

② Aluminum Plates

③ Emulsion Stacks

④ Thermocouples — copper-constantan

⑤ Heat Sink — methanol + dry ice

The heat source was a 100 watt, 30 ohm resistor. The current flow through the resistor was used to control the temperature of the heat source. The heat sink was at the temperature of a dry ice and methanol mixture.

Emulsions at normal humidity (50-60%) will fuse together when heated to temperatures of 50° to 60° C, but dry emulsions will withstand temperatures in excess of 100° C without sticking. Therefore, by using dry emulsions, a temperature span of -20°C to 100°C was possible.

The apparatus was loaded in the darkroom placing the thermocouples at measured distances from the hot or cold end of the emulsion stack so that the temperature could be measured as a function of position. Black paper was placed around the stack to prevent light exposure and reaction of the emulsion with the aluminum. When the stack was in place and the source and sink attached, all exposed areas were covered with fitted pieces of styrofoam and all seams taped in order to provide thermal insulation.

About an hour was required to reach steady state; in order to reach steady state as soon as possible the resistor was turned on first, allowing the heating to proceed for about 5 minutes before the dry ice-methanol mixture was added. This particular process was established by trial.

After each run the emulsion was removed in the darkroom and if it was to be irradiated it was exposed to Co^{60}.

Mounting and developing methods can be found in sections 2.E and 2.F.

Results of temperature gradient experiments can be found in section 3.A.

D. Eradication Methods

A common problem encountered with nuclear research emulsions is the

presence of unwanted fog and track background. Even supposedly fresh emulsions have been received from the manufacturer with an intolerable number of electron tracks, and such condition is almost universal after a few months, unless emulsions are stored in a carefully prepared area free from cosmic and other incidental radiation. Furthermore, our data have indicated that increased fog background can easily be achieved by prolonged heating of emulsions. Therefore, we have included some experiments on eradication of the latent image.

It is known that subjecting emulsions to 100% relative humidity at 35° C will cause a loss of latent image. [4] This process is called eradication. The constant temperature oven was used to maintain the required temperature of 35° C. Maintaining 100% relative humidity was first attempted by using a metal developing tray in which a Plexiglas rack with four shelves arranged vertically was placed. Emulsion pellicles cut in 3/4 by 2-1/2 inch strips were placed on the shelves and a small amount of water placed in the metal tray. The tray was then sealed with tape and placed in the oven. However, this arrangement proved unsatisfactory, since a humidity gradient which formed in the container resulted in different conditions at the four shelves.

A shallow plastic tray with an airtight cover was then tried. This allowed one large shelf, about one inch above the water surface, on which all pellicles were placed. However, condensation which collected on the cover of the tray dripped down on the emulsion pellicles. To prevent this "rain" a number of holes were drilled in the cover to allow excess water vapor to escape and the tray was put into the oven on a slight incline to ensure that any condensation which did form would drip off harmlessly at one end of the tray away from the emulsion. This arrange-

ment successfully maintained 100% relative humidity in the container and was employed for all eradication experiments.

Eradication times were varied from 1 day to 6 days in order to determine the dependence of eradication on the length of time the pellicles were maintained at 100% relative humidity and 35° C. Experimental results are given in section 3.B, and indicate that a majority of the fog background is eradicated during the first 24 hours and also that electron tracks are eliminated at least as rapidly as fog background.

E. Mounting Procedures

To facilitate processing and scanning of the emulsions and to provide additional mechanical strength, it was necessary to mount the emulsion pellicles on glass plates. The Heckman method, one of several procedures described by Barkas for mounting emulsion pellicles on glass, was chosen as the method to be used throughout our experiment. [5]

Consistently good results were obtained by this method when mounting normal fresh emulsion pellicles. However, mounting of pellicles after removal from the oven was difficult because the pellicles were usually warped and quite brittle. To soften the warped pellicles sufficiently to obtain a good bond between the emulsion and the glass, they were soaked in a 65% alcohol bath for two minutes instead of the one minute described by Barkas. [5]

When eradicated pellicles were mounted and then processed, a large number of blisters formed between the pellicles and the glass and sometimes pellicles peeled off the glass during processing. We can not explain this behavior, although we found that mounting the pellicles prior to eradication resulted in considerably less blistering and peeling during processing.

F. Processing Methods

The Bristol Developer method was used to process the mounted emulsion pellicles. [6] The compositions of the developer and other standard processing solutions used are listed in Table I.

The processing times in each solution for the 200μ and 300μ emulsions and the temperature of the solutions are listed in Table II.

Table I

Composition of Standard Processing Solutions

Bristol Developer Cold Stage		
Distilled water	1.0	liter
Sodium sulfite, Anhy.	7.2	grams
Sodium bisulfite, Meta	1.0	gram
Potassium bromide	0.87	gram
Amidol	3.25	grams
Bristol Developer Warm Stage		
Distilled water	1.0	liter
Sodium sulfite, Anhy.	7.2	grams
Sodium bisulfite, Meta	1.0	gram
Potassium bromide	0.87	gram
Amidol	1.3	grams
Short Stop		
Distilled water	1.0	liter
Acetic acid, Glacial	31.0	milliliter
Fixing Bath		
Distilled water	1.0	liter
Sodium bisulfite, Meta	22.5	grams
Sodium thiosulfate	300.0	grams

In addition to the normal processing method described above, variations in processing were used. The warm stage development was completely omitted and processing with cold stage development only, for times of $2\frac{1}{2}$, $1\frac{1}{2}$, and $\frac{1}{2}$ hour, was carried out for some of the stacks. This was done to determine whether the fog background could be suppressed

Table II

Processing Times and Temperatures

Solutions	Degree C	200	300
Cold Soak	3-5	20 min	40 min
Cold Develop	5	20 min	40 min
Hot Develop	22	50 min	50 min
Stop Bath	5	20 min	40 min
Fixer	5	(Clearing time 50%)	
Dilution & Wash	5-10	(Demineralized water at 3% of tank volume until hypo test is negative)	
50% Alcohol & 5% Glycerin	5-10	20 min	40 min
75% Alcohol & 5% Glycerin	10	20 min	40 min
95% Alcohol & 5% Glycerin	10 to Room temp	1 hour	1½ hour

relative to the blob density of electron tracks by variations in development. No substantial improvement in the quality of the processed emulsions was observed.

To insure uniform processing for all the pellicles of a given stack, the plates were placed in racks and always processed together. Fresh solutions were always used, and the amidol developer was never mixed more than an hour or so before it was to be used.

To avoid etching in the fixing bath, the silver ion concentration was not allowed to exceed 10 grams per liter, and we attempted to maintain about 6 grams per liter throughout the fixing. No improvement was noted in those cases in which the hypo was pre-loaded with silver to about three grams per liter.

G. Scanning Procedures and Data Reduction

To determine fog background, the total number of separate blobs in a defined volume of emulsion was counted. The top and bottom 10μ of the

processed emulsions were always excluded from measurement in order to avoid surface effects.

The counting was done using a 100X objective and 10X oculars. A rectangular reticle measuring 28 by 31μ was constructed of spider web and placed in one of the oculars in order to define the region in which blobs were to be counted. The small rectangle size was chosen to enable the scanner to cover the area of view easily without confusion from the presence of too many blobs in focus simultaneously as a traversal in the Z direction was made. The Z dimension was corrected for shrinkage by multiplying by the ratio of original thickness to processed thickness (S). The volume of unprocessed emulsion scanned was caluclated from the corrected Z and the calibrated reticle area. The total number of fog grains was then divided by the total volume to give the N/V ratio in blobs/$10^3\mu^3$ of unprocessed emulsion.

In order to estimate emulsion sensitivity the blobs produced by fast electrons were counted. The tracks counted were those of Compton and photoelectric electrons produced during the Co^{60} exposures. Electron tracks that were fairly straight, flat, and long enough to be equal to or greater than 2 lengths of the rectangle (31μ) were counted. Each segment of track counted was aligned along the length of the rectangle and the number of separate blobs was counted. This procedure was repeated on a number of tracks, noting the number of lengths traversed, until a total count of at least 400 blobs was obtained. Each data point thus has a statistical uncertainty of about 5%.

This method of counting is subject to individual biases among observers in the selection of tracks to be counted and probably from other subjective criteria. In order to estimate the importance of these

differences, certain regions of several pellicles were counted by several observers. No consistent normalization between observers has been applied to our data, but it is estimated that the accuracy of each data point is reduced to about 10% by the variations among observers.

H. Thermal and Mechanical Properties

The thermal conductivity of emulsion was measured at relative humidities of 0, 60, and 100%. The procedure used involved measuring the rate of heat transfer through a slice of emulsion (one or more 300μ pellicles). A metal tank filled with hot water and insulated on all sides except the bottom was used as the heat source, and a 646-gm copper block embedded in styrofoam was used as the heat sink. Two copper-constantan thermocouples were used to measure the temperature difference between the bottom of the metal tank and the copper block during the heat transfer process. Galvanometer readings of the potential difference between the thermocouples were recorded every minute for ten minutes. Data points were plotted on a semi-logarithmic graph, with galvanometer readings on the log axis and time on the linear axis (see Fig. 18). The slope of a straight line fitted through these points was measured and the thermal conductivity K calculated using the equation:

$$K = -\frac{2.3aLMC}{A} \quad \left(\frac{\text{calories}}{\text{cm-sec-}^{\circ}\text{C}}\right),$$

where a is the slope of the straight line in sec^{-1}, L is the thickness of the emulsion slice in cm, M is the mass of the copper block in gm, C is the specific heat of copper ($=0.093 \frac{\text{calories}}{\text{gm-}^{\circ}\text{C}}$), and A is the area in cm^2 of the upper face of the copper block. Results of these measurements are discussed in section 3.B.

The Brinnell hardness of emulsion was also measured for relative humidities of 0, 60, and 100%, using the method outlined by Barkas. [7]

This method involves measuring the diameter of the depression made in the emulsion by a loaded sphere pressed into the surface. The hardness is then calculated from the formula:

$$\text{Brinell hardness} = \frac{2M}{\pi D\left[D - \left(D^2 - d^2\right)^{\frac{1}{2}}\right]}$$

where M is the load in kg, D is the sphere diameter in mm, and d is the depression diameter in mm. Results of these hardness measurements are discussed in section 3.C, and indicate a rapid softening of emulsion as relative humidity increases.

3. Experimental Results[1]

A. Photographic Properties

(1) The functional dependence of fog background and of emulsion sensitivity to particles near the minimum of ionization was investigated through two separate techniques, the constant temperature method and the temperature gradient method.

(a) The constant termperature method used 3/4 by 2-1/2 inch pellicles of 200 and 300μ emulsion heated at 55°or 60°C for periods ranging from 0 to 16 days. Dry emulsion was used throughout except for control plates. The plates labeled 0 days in the graphs were dry unheated emulsions. At the end of each experiment the pellicles were mounted on 1 by 3 inch glass and were then exposed to Co^{60}. These stacks are numbered 1 through 3.

Stack 1 was 300μ emulsion heated at 60°, with emulsions being added to the oven at four day intervals. The maximum heating time was 16 days. Four processing techniques were used; normal, 2-1/2 hour cold stage only, 1-1/2 hour cold stage only, and 1/2 hour cold stage only. The variation of fog density as a function of days heated is shown in Figs. 2 through 4. The K.5 emulsion doubled in fog density at 4 days of heating for the normal processing and the 8 day plate was black. The other processing methods showed a similar behavior with a later rise in the fog density. G.5 emulsion with normal processing reached a doubling density at 7 days and was opaque at 10 days, while the other processing methods again showed a later increase in fog. G.2 emulsions with normal processing reached a doubling density at 8 days, however, the initial background fog was low, and these emulsions were qualitatively much less affected by heating.

[1]To provide greater clarity data points are not shown on each curve in some figures. The points shown are representative of the experimental scatter for each curve of the figure.

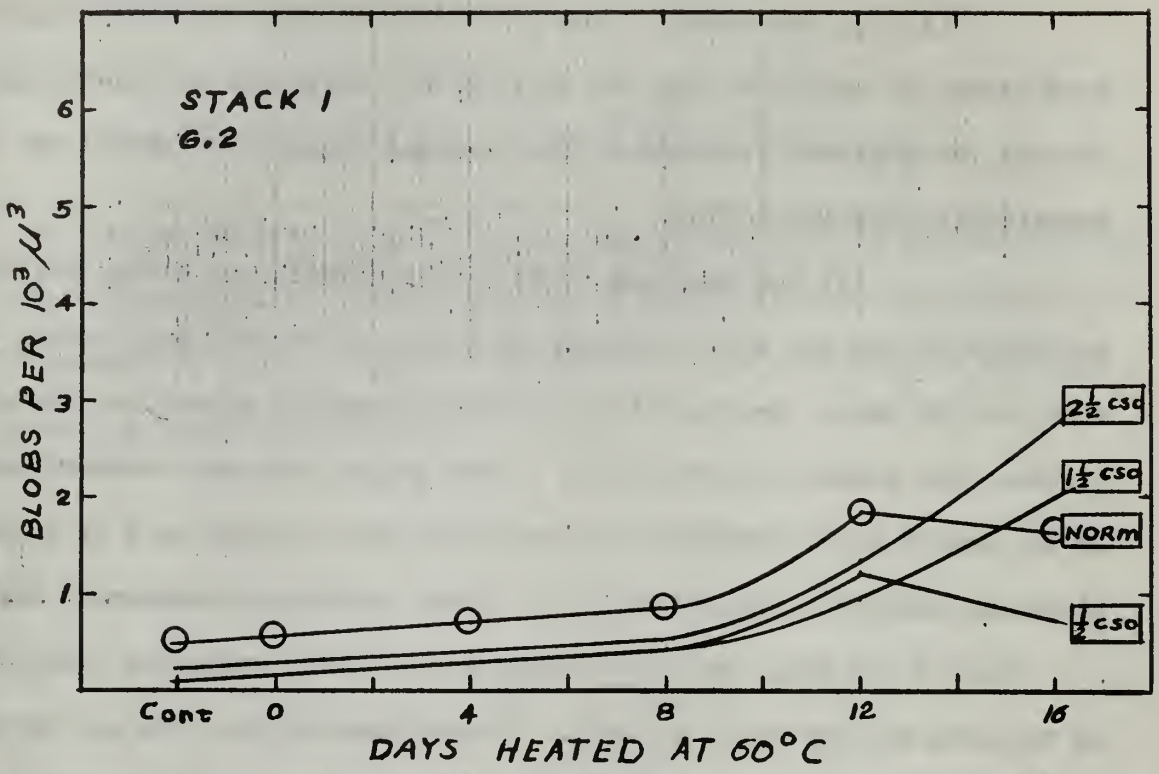


FIG.2. CONSTANT TEMPERATURE, FOG DENSITY VS. TIME

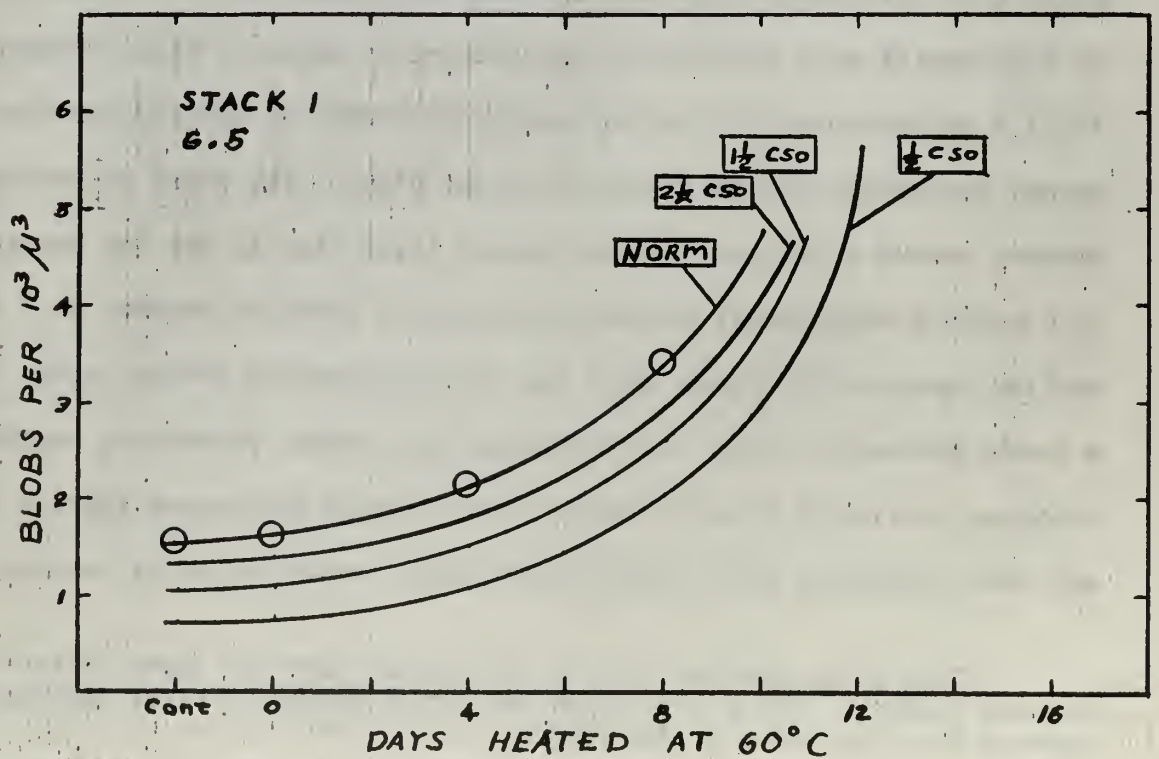


FIG.3. CONSTANT TEMPERATURE, FOG DENSITY VS. TIME

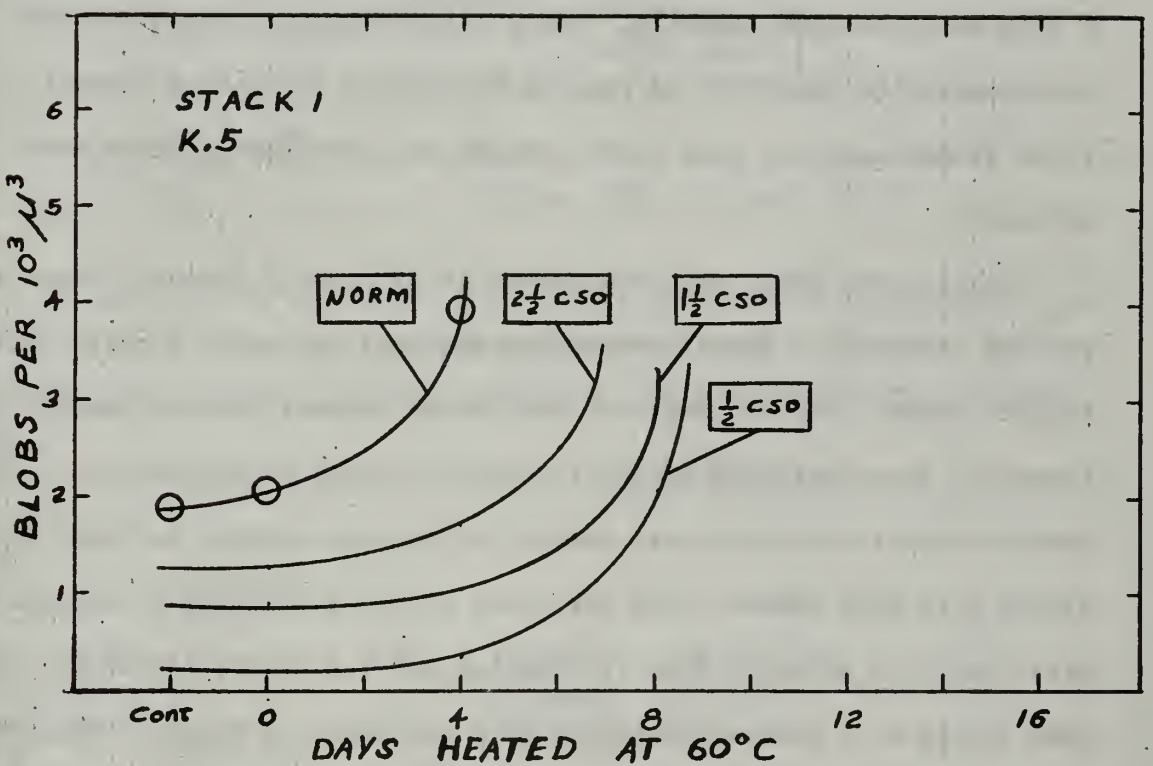


FIG. 4. CONSTANT TEMPERATURE, FOG DENSITY VS. TIME

The change in emulsion sensitivity to minimum tracks as a function of days heated is shown in Figs. 5 and 6. While there was a definite increase in the blob density of these tracks, reference to Figs. 2, 3, and 4 shows that the fog background always increases enough to offset any advantage in resolution of the tracks. This is in contradiction to the data of reference [1]. G.2 emulsions are not sensitive to minimum tracks, so no data on sensitivity are obtained from the Co^{60} exposures.

Stack 2 was 300μ emulsion heated at 60°C for 1 day intervals up to 8 days and developed normally. Heavy silver deposits formed on the emulsions which could not be removed by rubbing with ethyl alcohol. These slides were too dark to be scanned and therefore no data were obtained.

Stack 3 was 300μ emulsion heated at 55°C for 4 through 9 days at one day intervals. Normal processing was used but again a heavy silver deposit formed with the depth of the silver deposit proportional to the number of days heated, an effect for which we have no explanation. The surface deposit of silver was removed with ethyl alcohol and most of the plates were then usable. The variation of fog density as a function of days heated is shown in Fig. 7. The K.5 and G.5 plates heated for longer than 6 days or 7 days respectively were not usable because of the heavy silver deposits.

The change in electron track blob density as a function of days heated is shown in Fig. 8. Again, some increase in sensitivity to minimum tracks is evident. The lack of increase in fog for this stack is not clearly understood, but if the data are to be interpreted literally, this indicates a significant difference in heating at 55°C vs 60°C. The data from the temperature gradient stacks lends some support to this possibility.

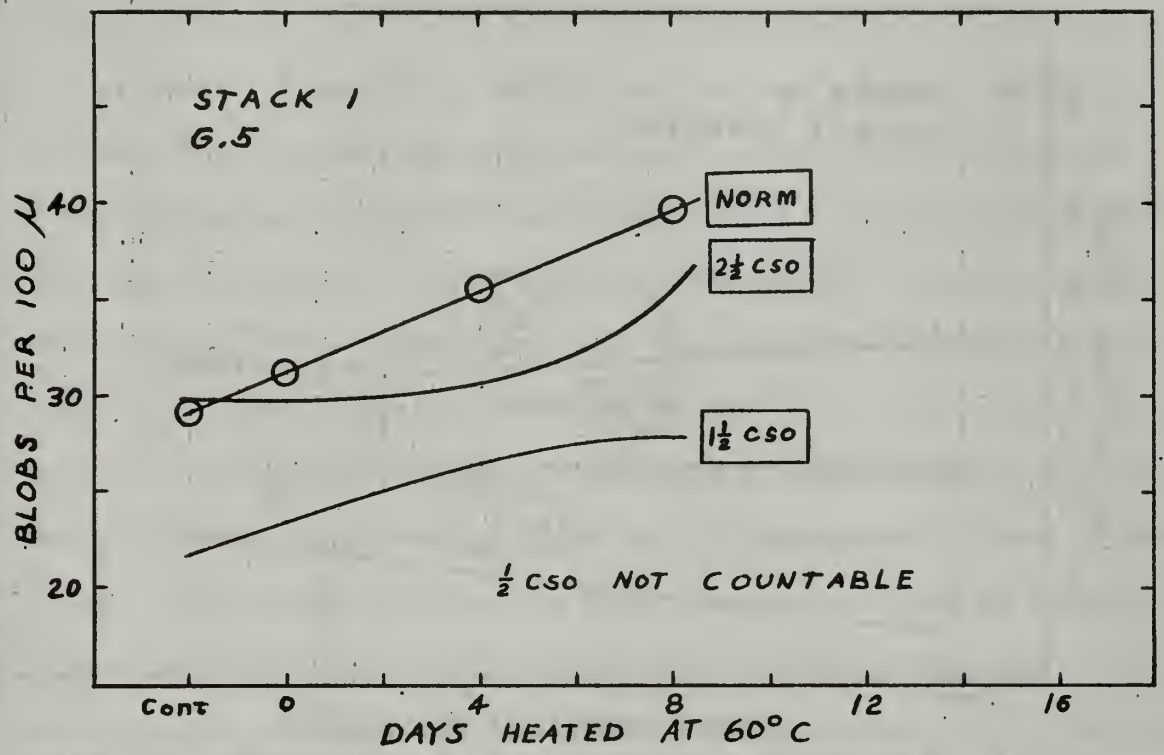


FIG. 5. TRACK BLOB DENSITY AS FUNCTION OF TIME

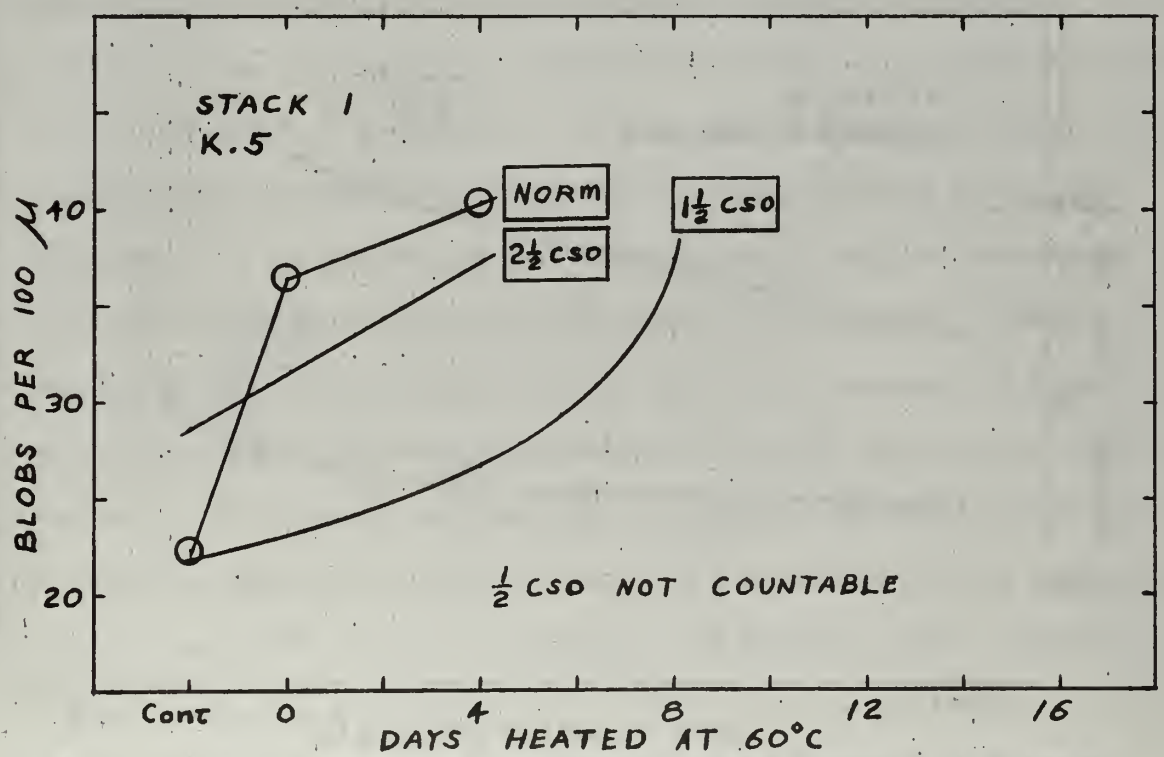


FIG. 6. TRACK BLOB DENSITY AS FUNCTION OF TIME

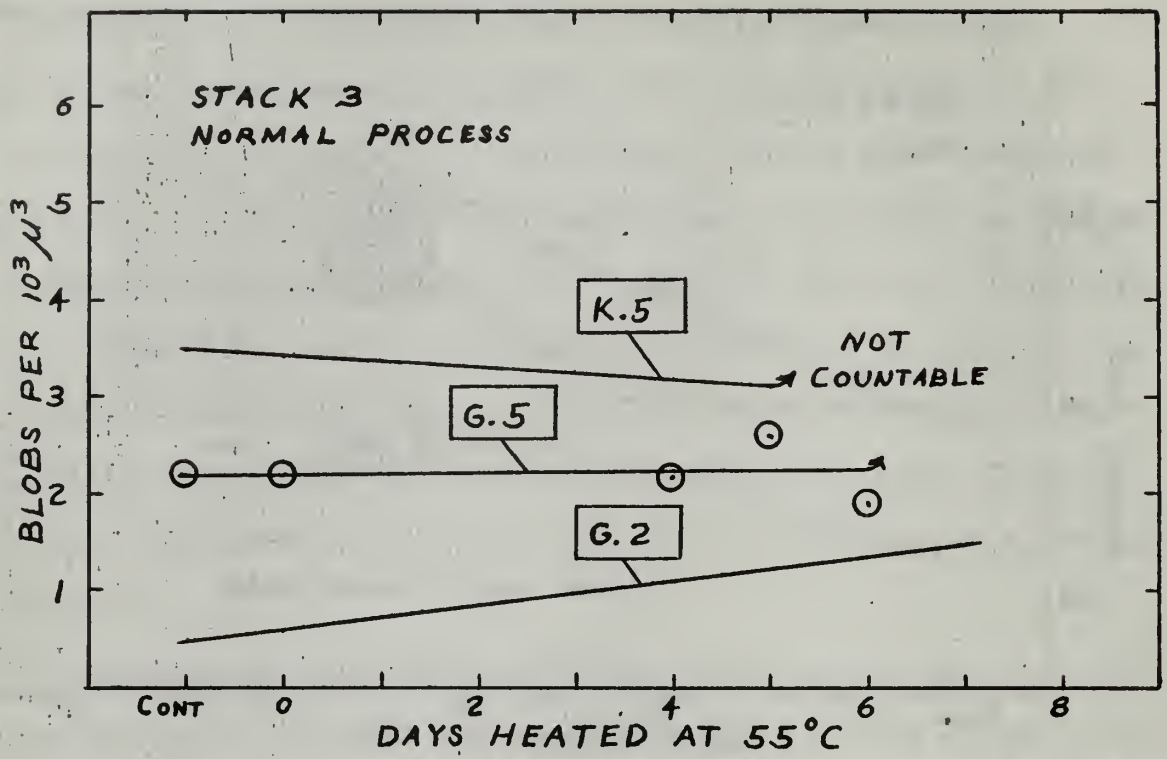


FIG. 7. CONSTANT TEMPERATURE, FOG DENSITY VS. TIME

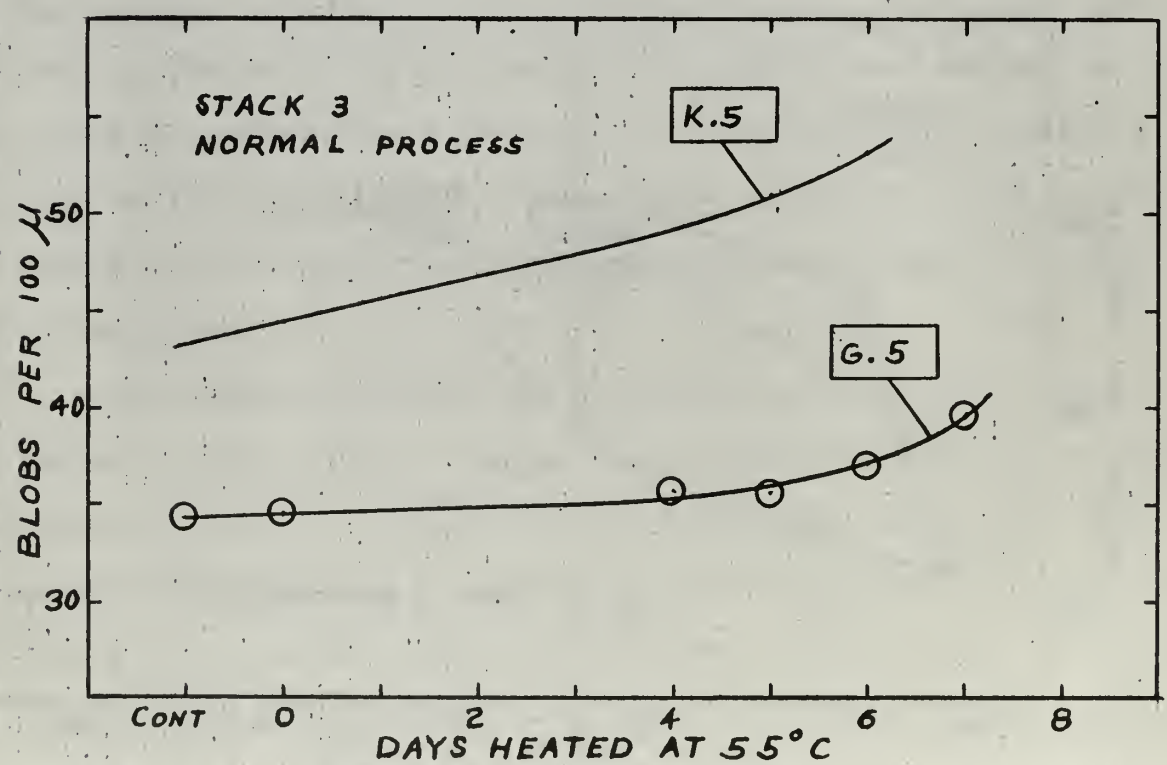


FIG. 8. TRACK BLOB DENSITY AS FUNCTION OF TIME

(b) The temperature gradient method used 3/4 by 6 inch strips of 200 and 300μ emulsion subjected to a temperature gradient ranging from -20° to +90°C for periods ranging from 1 to 24 hours, and in one sample, 7 days. Dry emulsion was used exclusively. At the end of each heating period the pellicles were mounted on 1 by 6-1/2 inch glass slides and processed by the normal method. The temperature gradient was maintained in stacks numbered 4 through 8 for 1, 2, 6, 12, 24 hours respectively. Stack 9 was held for 7 days while stack 10 was held only until steady state was established. Stacks 5, 6, and 8 were exposed to Co^{60}. The stacks 4 through 10 are shown as Figs. 9 through 11. Here the fog density is plotted as a function of temperature for each of these stacks. These data show that fog density increases slowly as a function of temperature until a certain temperature is reached where fog density increases very rapidly until the emulsion becomes opaque. This indicates that there is a critical temperature at which dry emulsion, even when heated for short periods, may be rendered useless by the increase in fog density. This temperature is slightly different for each type of emulsion, and is highest in G.2 emulsion. It is a general trend that longer heating times reduce the temperature at which a serious increase in fog is observed. It was found that dry emulsions may be held at temperatures of 40°C for 7 days with very little increase in blob density. However, G.5 and K.5 emulsions held at 60°C for 24 hours were increased in blob density by a factor of 3. G.2 exhibited the same increase when held at 65°C for 24 hours. It therefore appears that experimental emulsion should not be exposed to temperatures greater than 50°C for G.5 and K.5 and temperatures greater than 60°C for G.2 for periods of 24 hours if good resolution of minimum tracks is required.

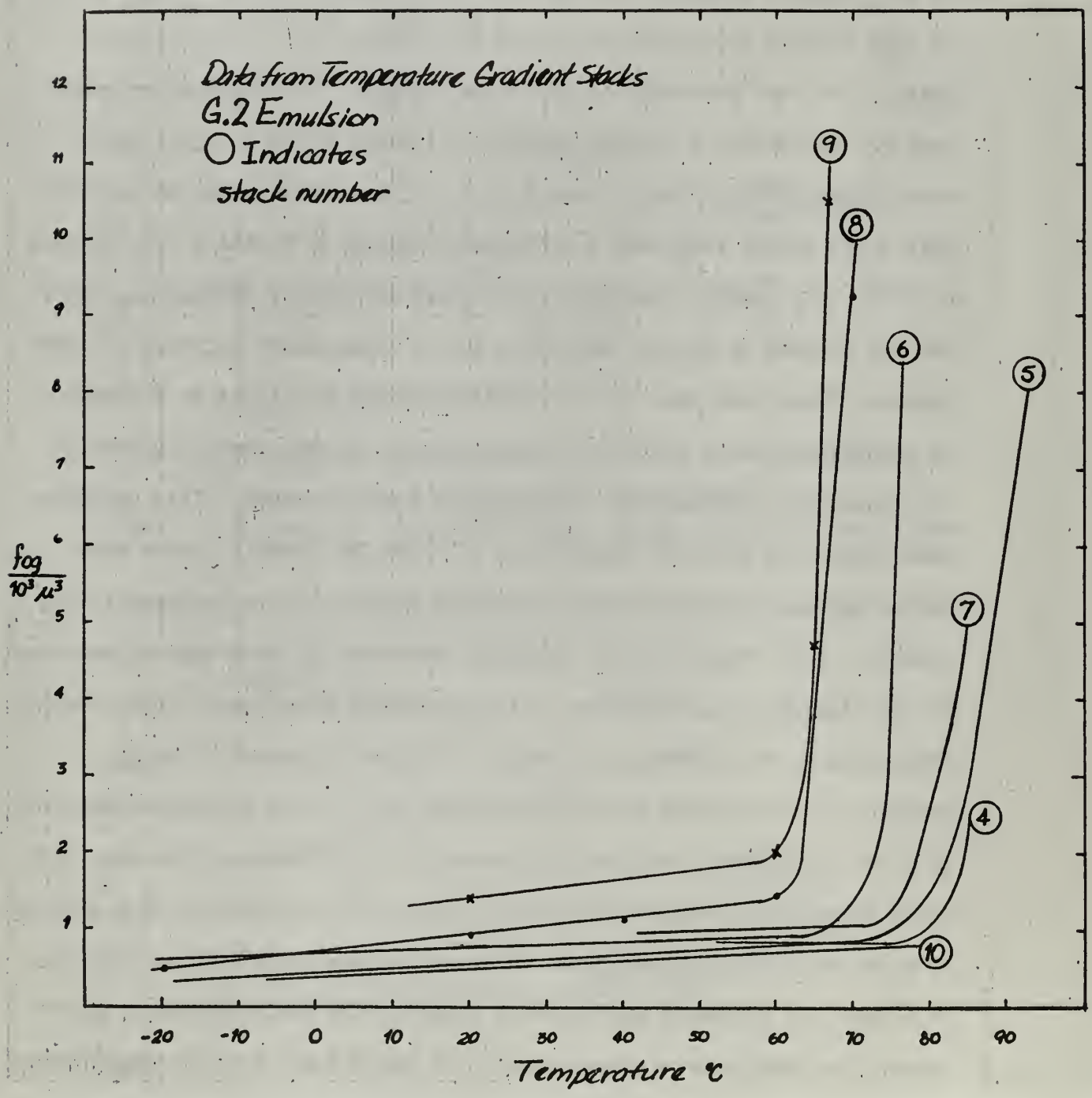

Data from Temperature Gradient Stacks
G.2 Emulsion
○ Indicates
stack number
9
8
6
5
7
4
10
fog
$10^3 \mu^3$
12
11
10
9
8
7
6
5
4
3
2
1
-20
-10
0
10
20
30
40
50
60
70
80
90
Temperature °C

Fig. 9.

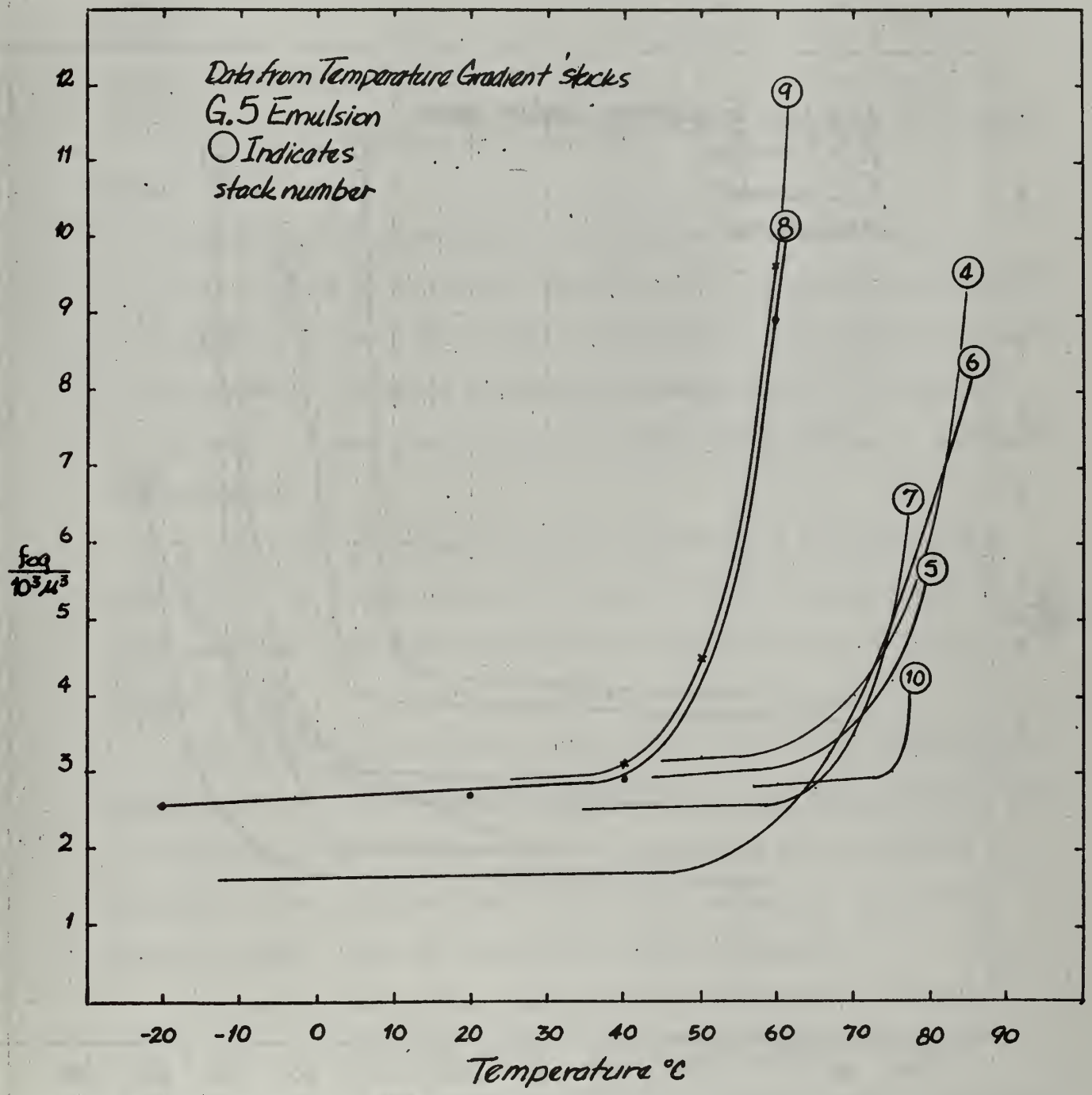

Data from Temperature Gradient stacks
G.5 Emulsion
○ Indicates
stack number
9
8
4
6
7
5
10
fog
$10^3 \mu^3$
12
11
10
9
8
7
6
5
4
3
2
1
-20
-10
0
10
20
30
40
50
60
70
80
90
Temperature °C

Fig. 10.

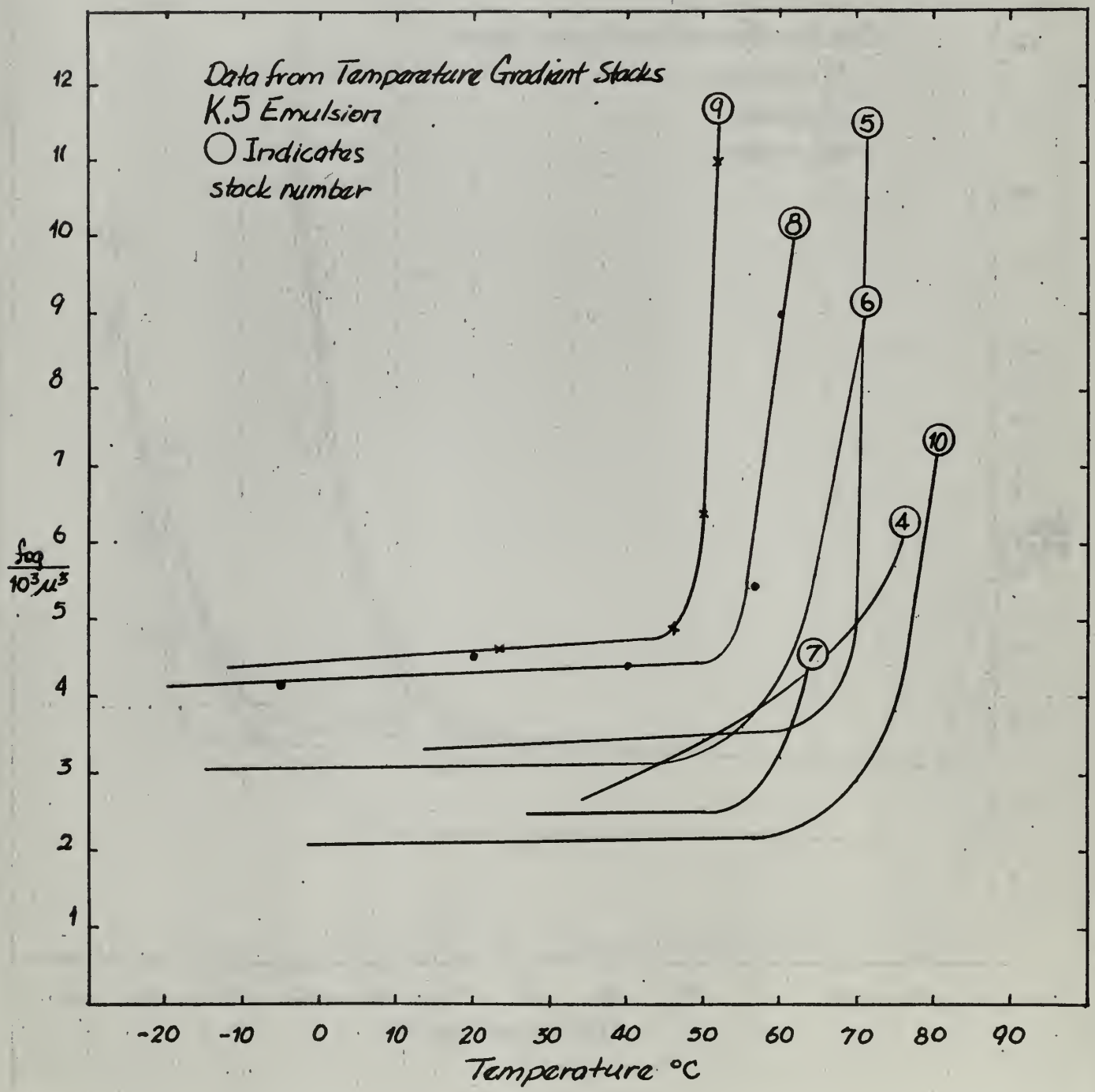

Data from Temperature Gradient Stacks
K.5 Emulsion
○ Indicates
stack number
9
5
8
6
10
4
7
fog
$10^3 \mu^3$
12
11
10
9
8
7
6
5
4
3
2
1
-20
-10
0
10
20
30
40
50
60
70
80
90
Temperature °C

Fig. 11.

In order to present the temperature gradient data in a form similar to the constant temperature method, Fig. 12 through 14 are shown. G.5 and K.5 data points from stacks 4 through 9 were normalized to 3 blobs/ $10^3\mu^3$ at 0°C. The points where fog density has increased by a factor of 2 tend to move toward shorter heating periods as the temperature of the isotherms increases. These findings agree with the constant temperature data.

Sensitivity to minimum tracks as determined from data from stacks 5, 6, and 8 showed no significant change over the temperature range when time held varied from 0 to 24 hours. This again indicates that no significant advantage is had by heating Ilford emulsion prior to exposure, and probably the most likely result is a deterioration caused by increased fog background.

(2) The investigation of the eradication of emulsions showed that most of the eradication occurred early in the eradicating period, using emulsions 200μ and 300μ thick for eradicating periods from 1 to 6 days.

Half of the 300μ pellicles from stacks 5 and 6 of the temperature gradient method of heating were eradicated for 6 and 3 days, respectively. In comparing the fog density between the eradicated and uneradicated emulsions, it was concluded that very little eradication had occurred after three days. This is illustrated by Figs. 15 and 16.

In view of these results, eradication of emulsions for periods from 1 to 3-3/4 days was attempted. It was found that most of the eradication occurred in about 24 hours, especially in G.5 and K.5 emulsions. After the 24 hours the eradication tended to level off as is illustrated by Fig. 17.

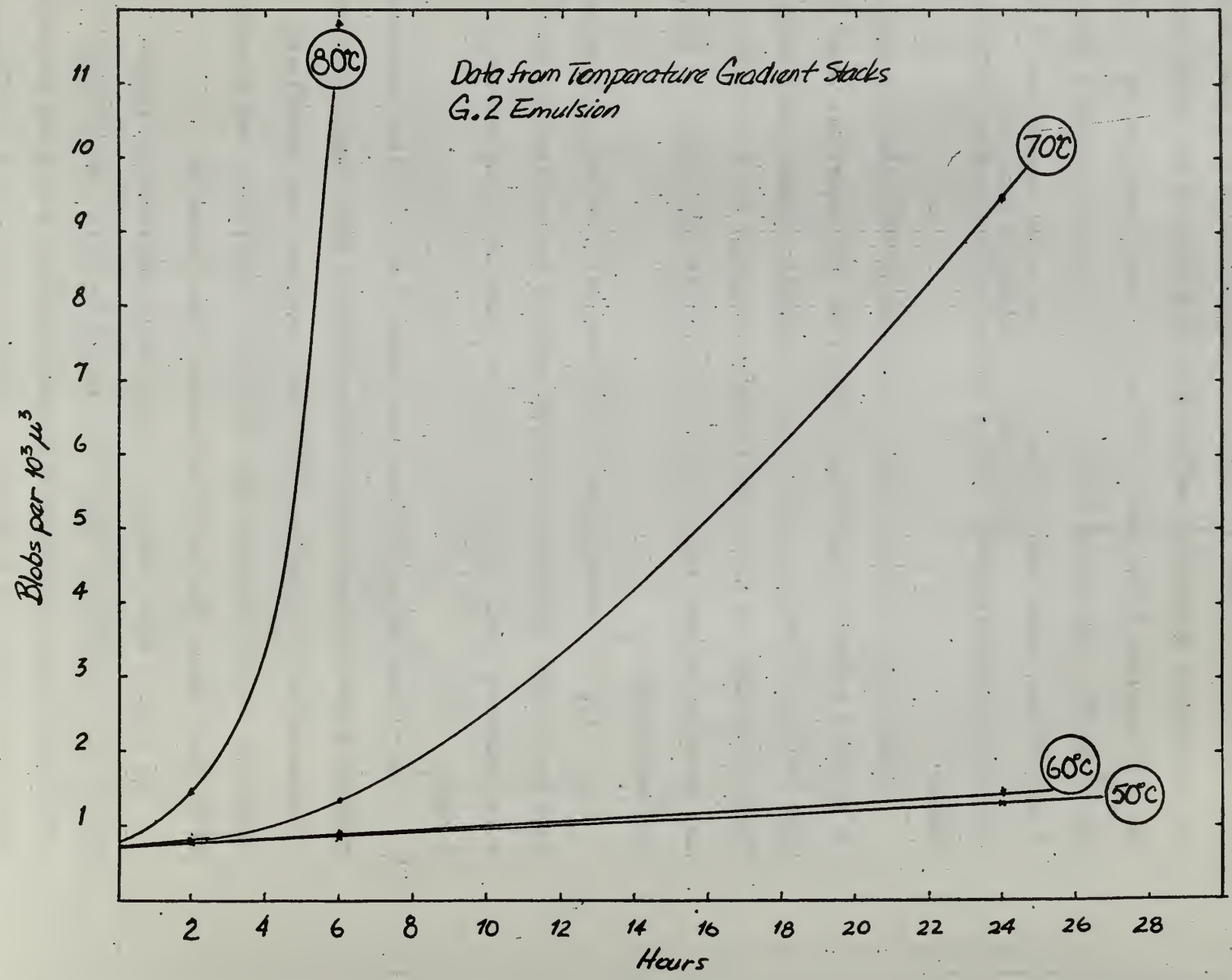

Data from Temparature Gradient Stacks
G.2 Emulsion
80C
70C
60C
50C
Blobs per $10^3 \mu^3$
Hours
1
2
3
4
5
6
7
8
9
10
11
2
4
6
8
10
12
14
16
18
20
22
24
26
28

Fig 12.

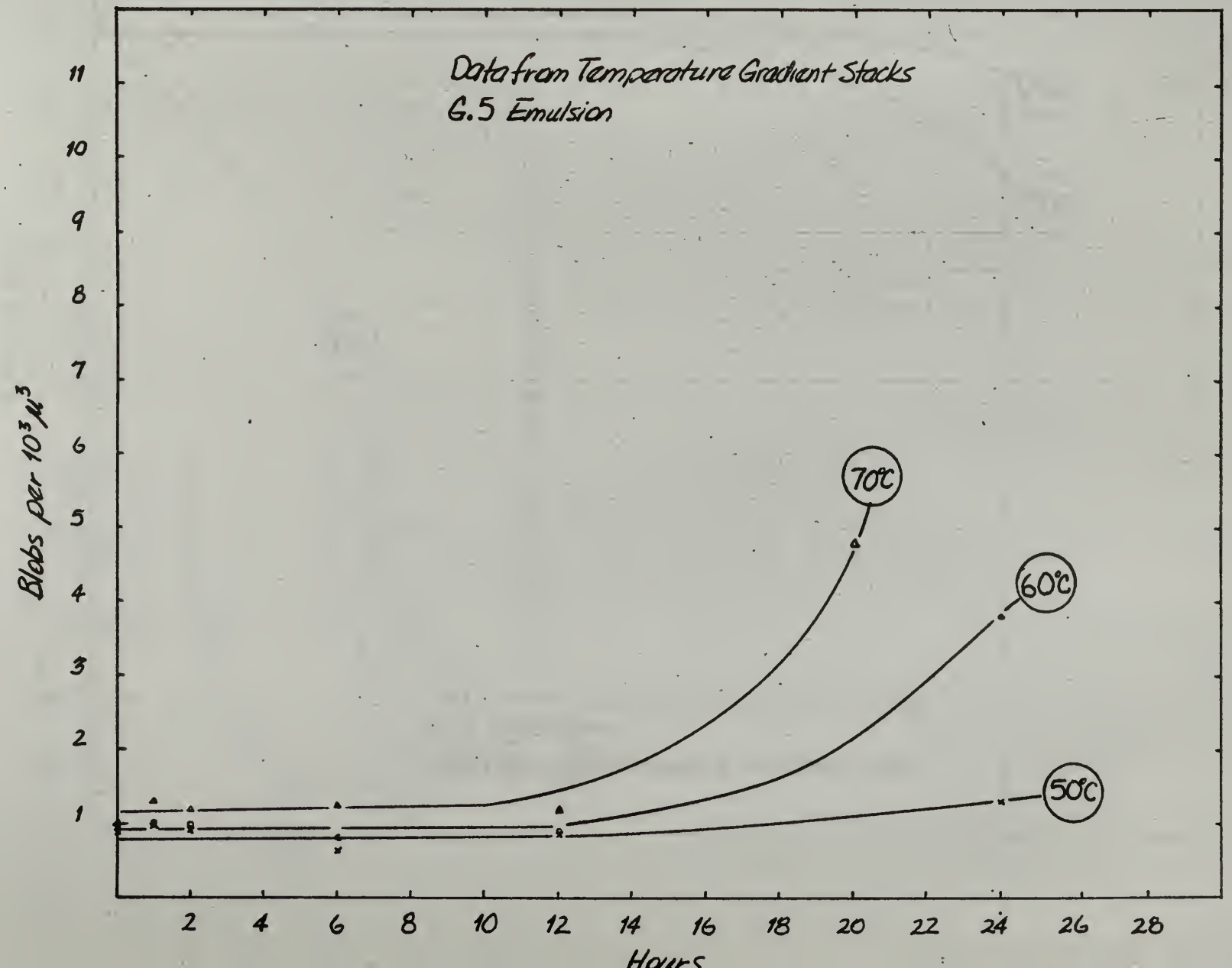

Data from Temperature Gradient Stacks
G.5 Emulsion
Blobs per $10^3 \mu^3$
11
10
9
8
7
6
5
4
3
2
1
70°C
60°C
50°C
2
4
6
8
10
12
14
16
18
20
22
24
26
28
Hours

Fig. 13.

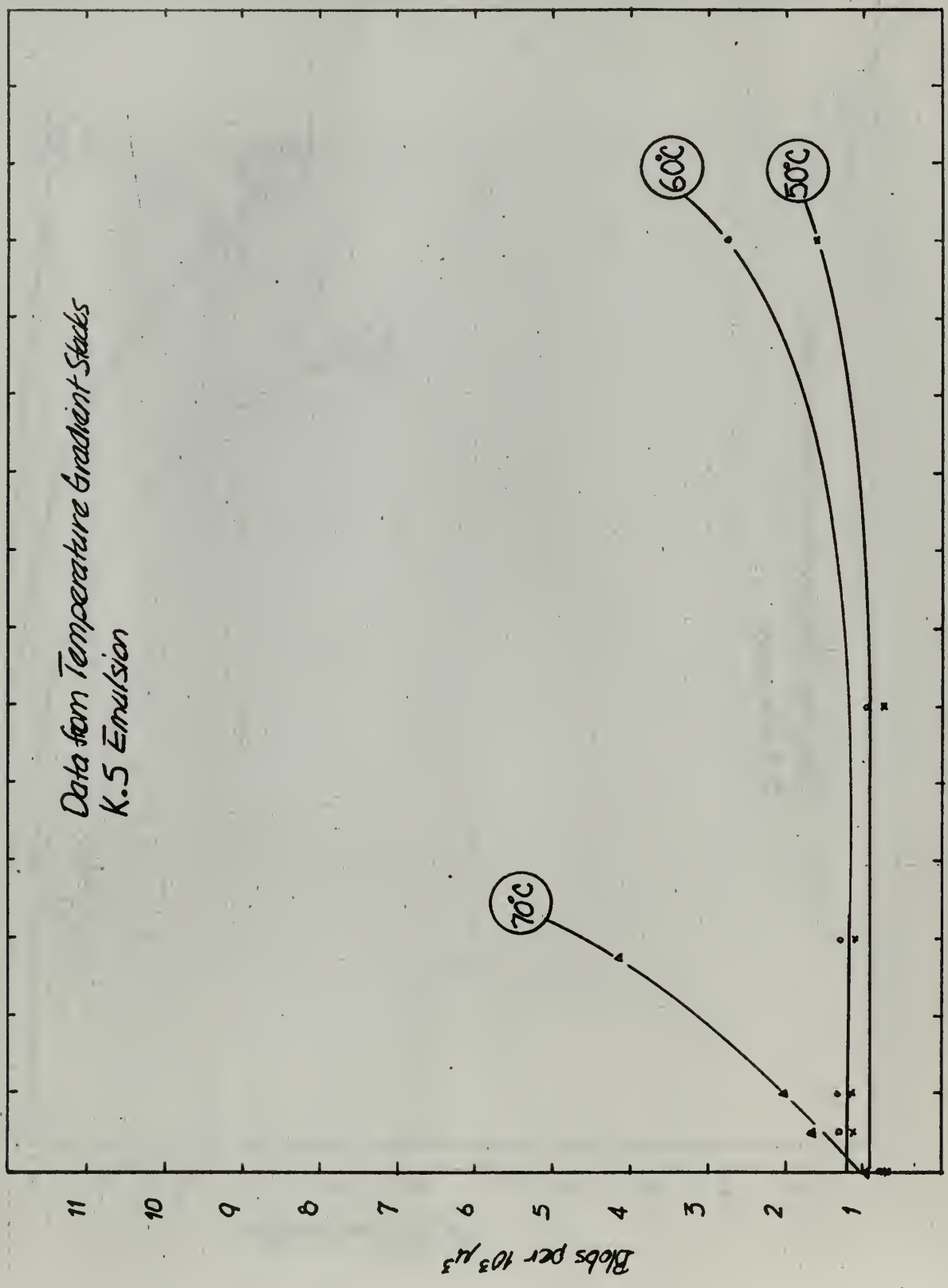

Data from Temperature Gradient Studies
K.5 Emulsion
70°C
60°C
50°C
Blobs per $10^3 \mu^3$
Hours
1
2
3
4
5
6
7
8
9
10
11
2
4
6
8
10
12
14
16
18
20
22
24
26
28

Fig. 14.

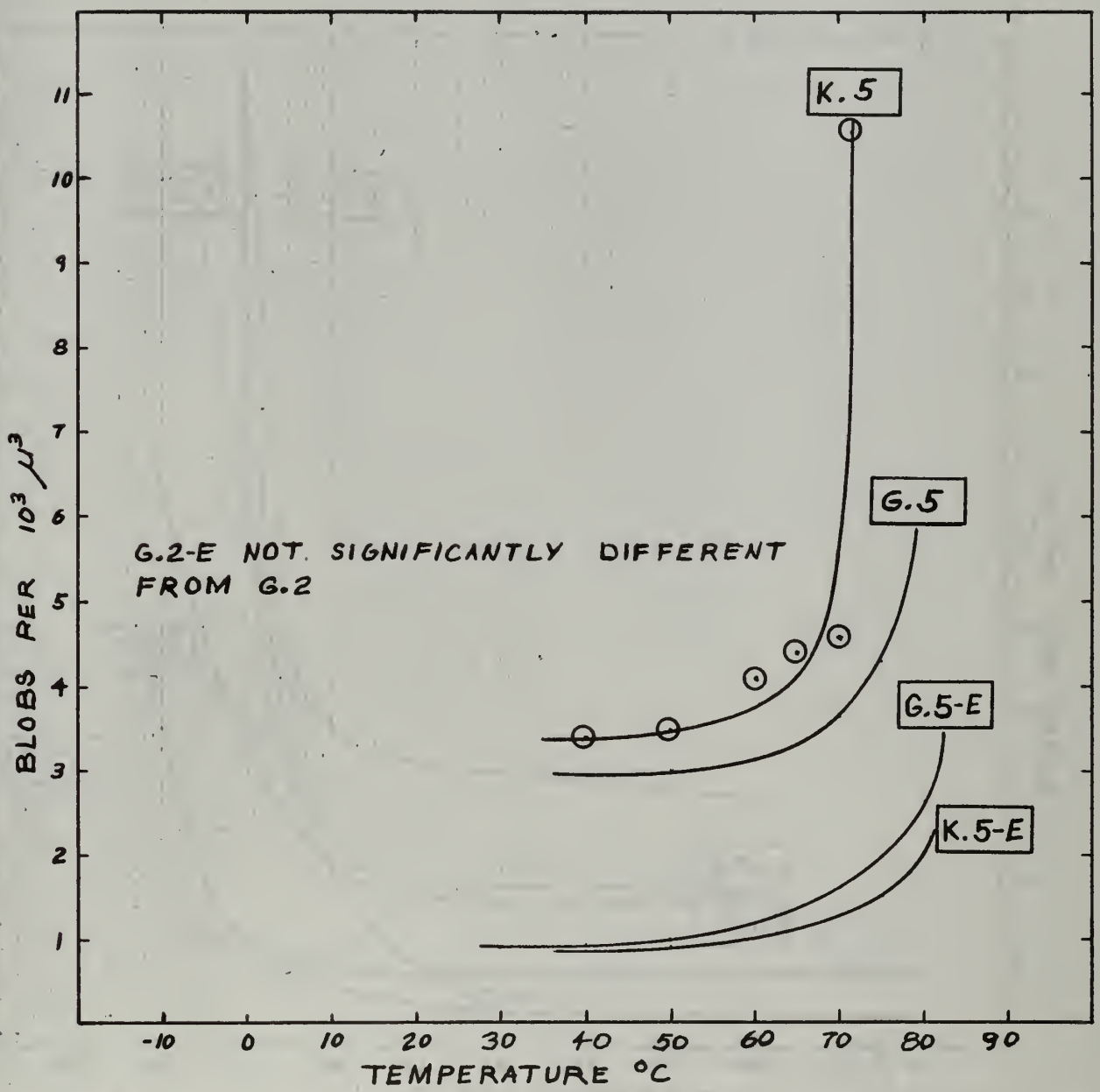


FIG. 15. TEMPERATURE GRADIENT SIX DAYS ERADICATION

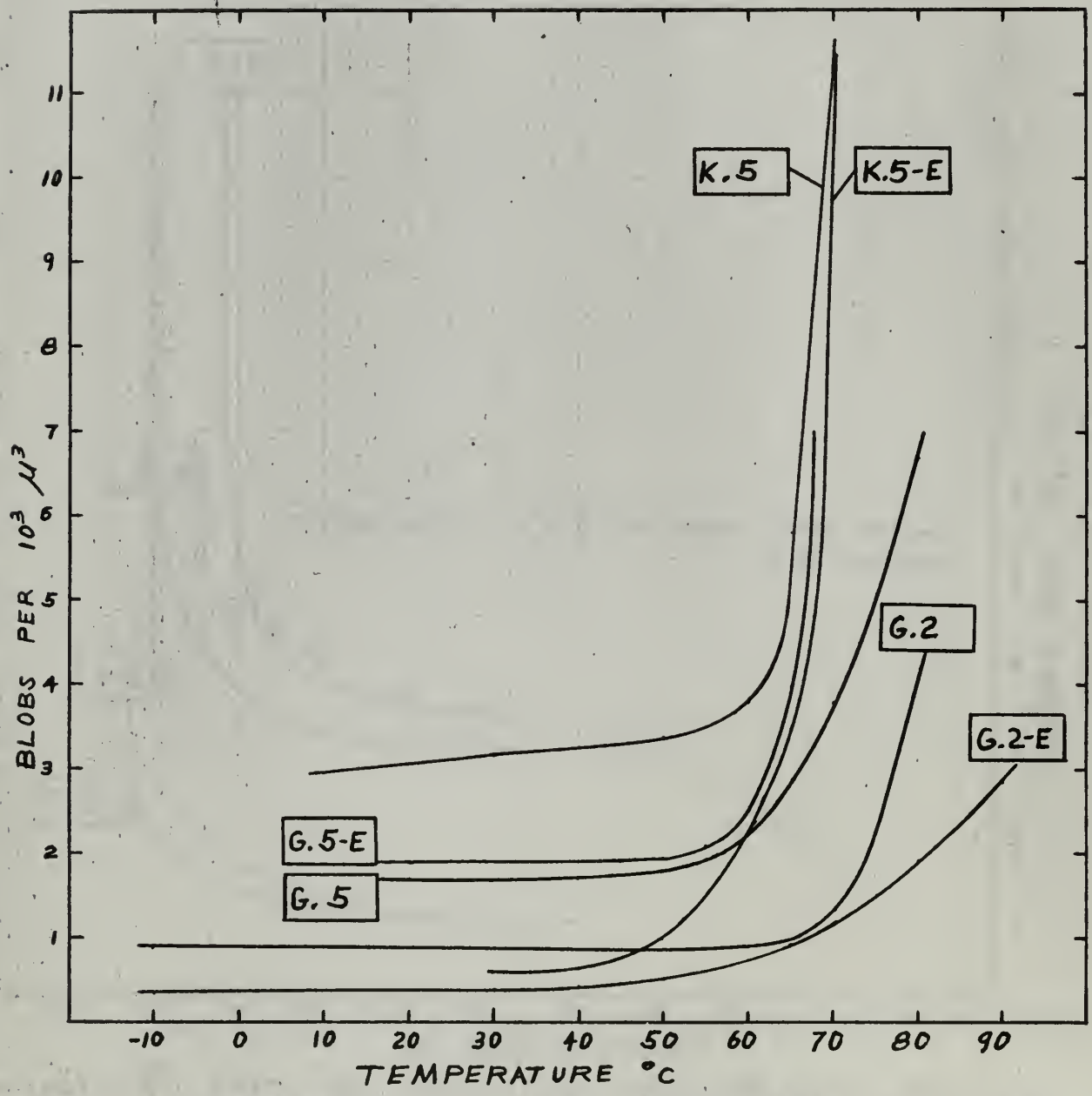


FIG. 16. TEMPERATURE GRADIENT THREE DAYS ERADICATION

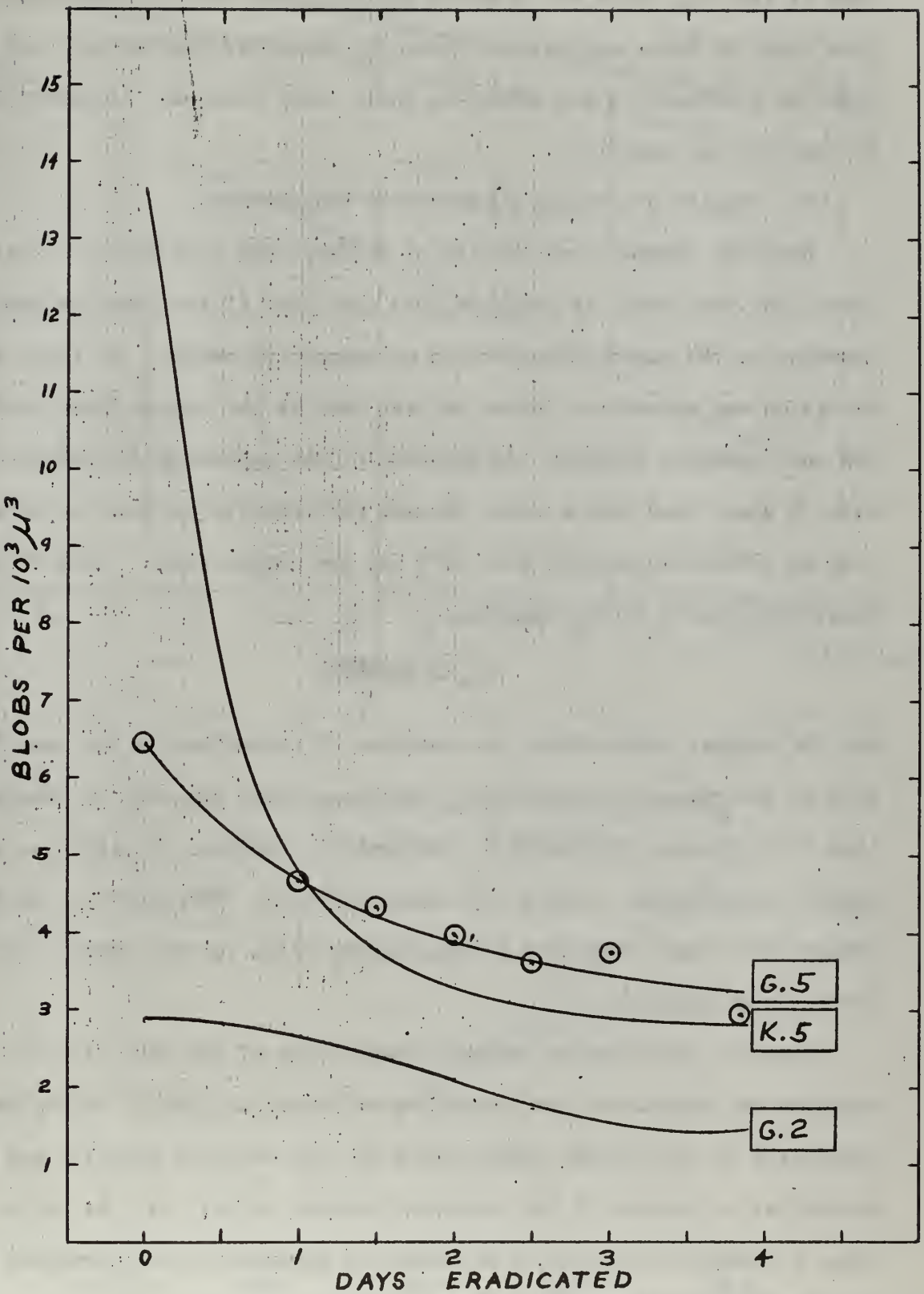


FIG. 17. FOG DENSITY AS A FUNCTION OF ERADICATION TIME.

It was also noted that the electron tracks eradicated at least as fast as the fog. This was observed qualitatively when obtaining the fog data from the 200μ plates. In fact, the three day eradication left no signs of electrons in the emulsions while there were many electron tracks in the zero day emulsions.

B. Results of Thermal Conductivity Measurements

When the thermal conductivity of emulsion was calculated, it was found that the value, as measured from the slope of the semi-log graph, depended on the sample thickness in an unexpected manner. At first this deviation was assumed to depend on heat lost by the copper block during the heat transfer process. Calibration of the apparatus was attempted using a glass slab with a known thermal conductivity in order to establish an effective specific heat (C^*) for the copper block. This C^* was substituted for C in the equation:

$$K = - \frac{2.3aLMC}{A},$$

and the thermal conductivity for emulsion of approximately the same thickness as the glass was determined. When an attempt was made to substitute this C^* in thermal conductivity equations for emulsion of different thicknesses, inconsistent results were again obtained. Therefore, we do not believe that these data give a satisfactory value for the thermal conductivity of emulsion.

However, the relative thermal conductivity of the same slab of emulsion was calculated for humidities of 0, 60, and 100%. Values were normalized to the thermal conductivity at zero relative humidity and are plotted as a function of the relative humidity in Fig. 19. As can be seen, a sharp rise in thermal conductivity apparently occurs between 60% and 100% relative humidity.

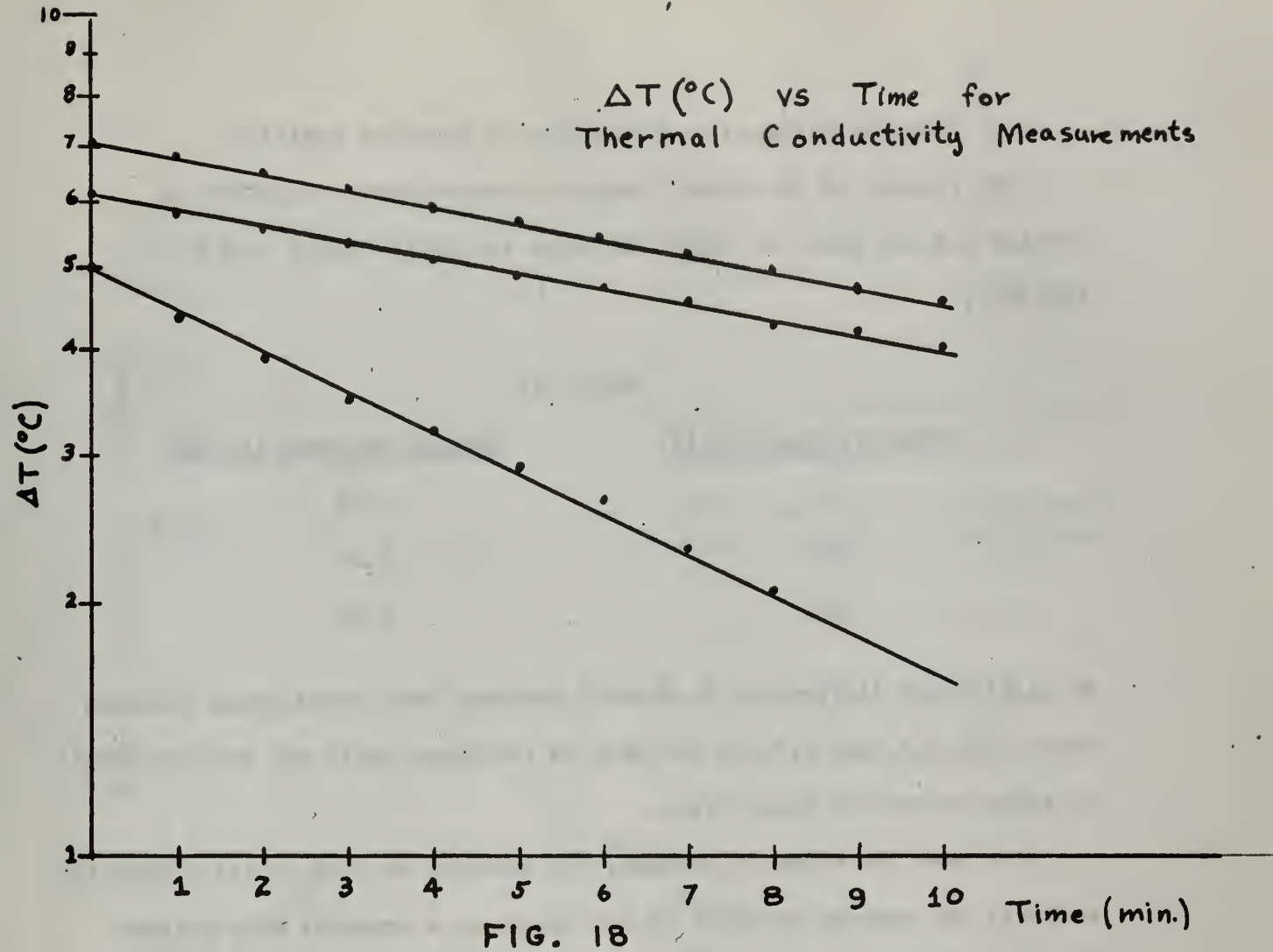

ΔT (°C) vs Time for
Thermal Conductivity Measurements
ΔT (°C)
10
9
8
7
6
5
4
3
2
1
1 2 3 4 5 6 7 8 9 10
Time (min.)

FIG. 18

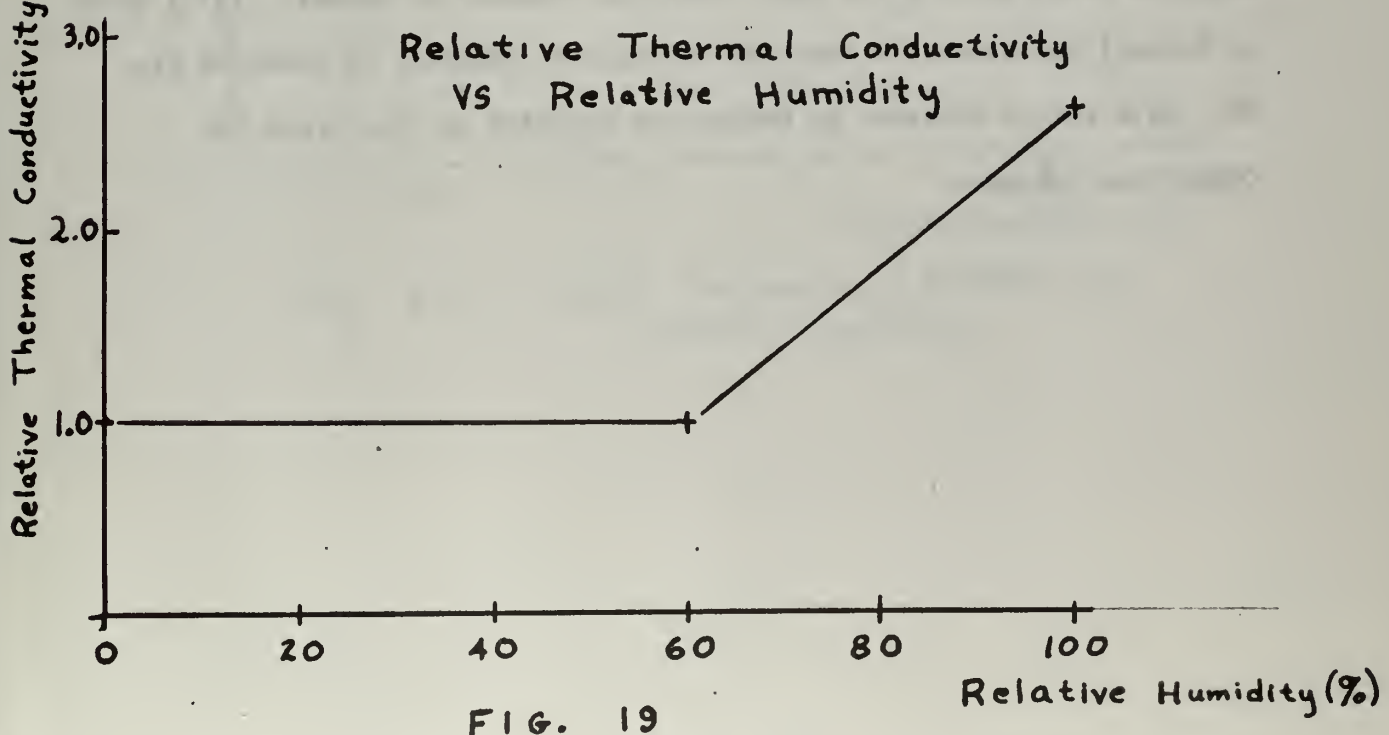

Relative Thermal Conductivity
vs Relative Humidity
Relative Thermal Conductivity
3.0
2.0
1.0
0 20 40 60 80 100
Relative Humidity (%)

FIG. 19

C. Emulsion Hardness as a Function of Relative Humidity

The results of the Brinell hardness measurements described in section 2.H are shown in table III below for 300μ Ilford type G.5 emulsion.

Table III

Relative Humidity (%)	Brinell Hardness (kg/mm^2)
0	7.70
60	3.25
100	0.09

No significant differences in Brinell hardness were noted among emulsion types G.2, G.5, and K.5, so the data in the above table may be considered to apply to each of these types.

The very low value of hardness for emulsion at 100% relative humidity reflects the extreme softness of wet emulsion, a property also noticed during eradication and processing. The 60% value of 3.25 kg/mm^2 compares with the value of 2.71 for 600μ emulsion obtained by Barkas. [7] A graph of Brinell hardness as a function of relative humidity is shown in Fig. 20. Data points obtained by Barkas are included in this graph for comparison purposes.

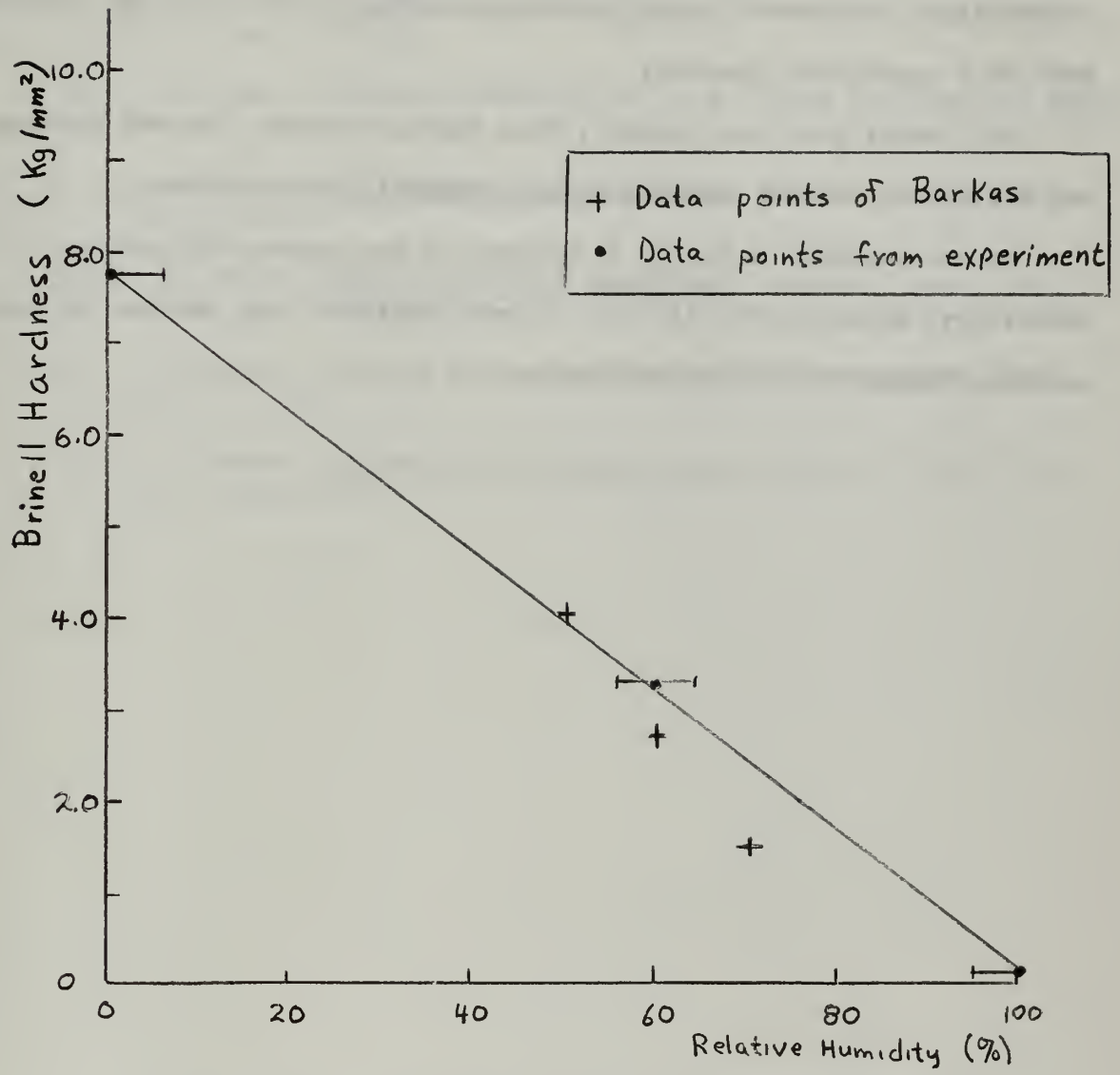


FIG. 20. Brinell Hardness of Emulsion vs. Relative Humidity

Acknowledgements

We are grateful to Dr. John N. Dyer for his continuing advice and leadership. His knowledge and experience in the field of nuclear emulsions made this experiment possible.

Out thanks go to our scanner, Miss Ingrid Anderson, for her arduous and meticulous work in counting several hundred thousand blobs.

We are indebted to Dr. H. H. Heckman of the Lawrence Radiation Laboratory, Berkeley, for the use of fresh emulsions and the loan of the scanning equipment used in this project.

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APPENDIX I

FOG IN PLATES VS FOG IN PELLICLES: A LATE RESULT

Late in this research study it was discovered that premounted emulsions showed substantially less fog background than pellicles mounted after heating, when both were heated for the same length of time. An attempt to investigate this occurrence was made by heating unmounted pellicles and prepoured plates together for periods of six and nine days. Both the plates and the pellicles were 200μ emulsion manufactured by Ilford on 10 January 1966, and had been kept in the same location since manufacture. The results of the fog background measurements are shown in Fig. 21, and indicate a significant difference between plates and pellicles for all emulsion types. We have no explanation for this result. It may indicate a real effect, however, and warrants further study.

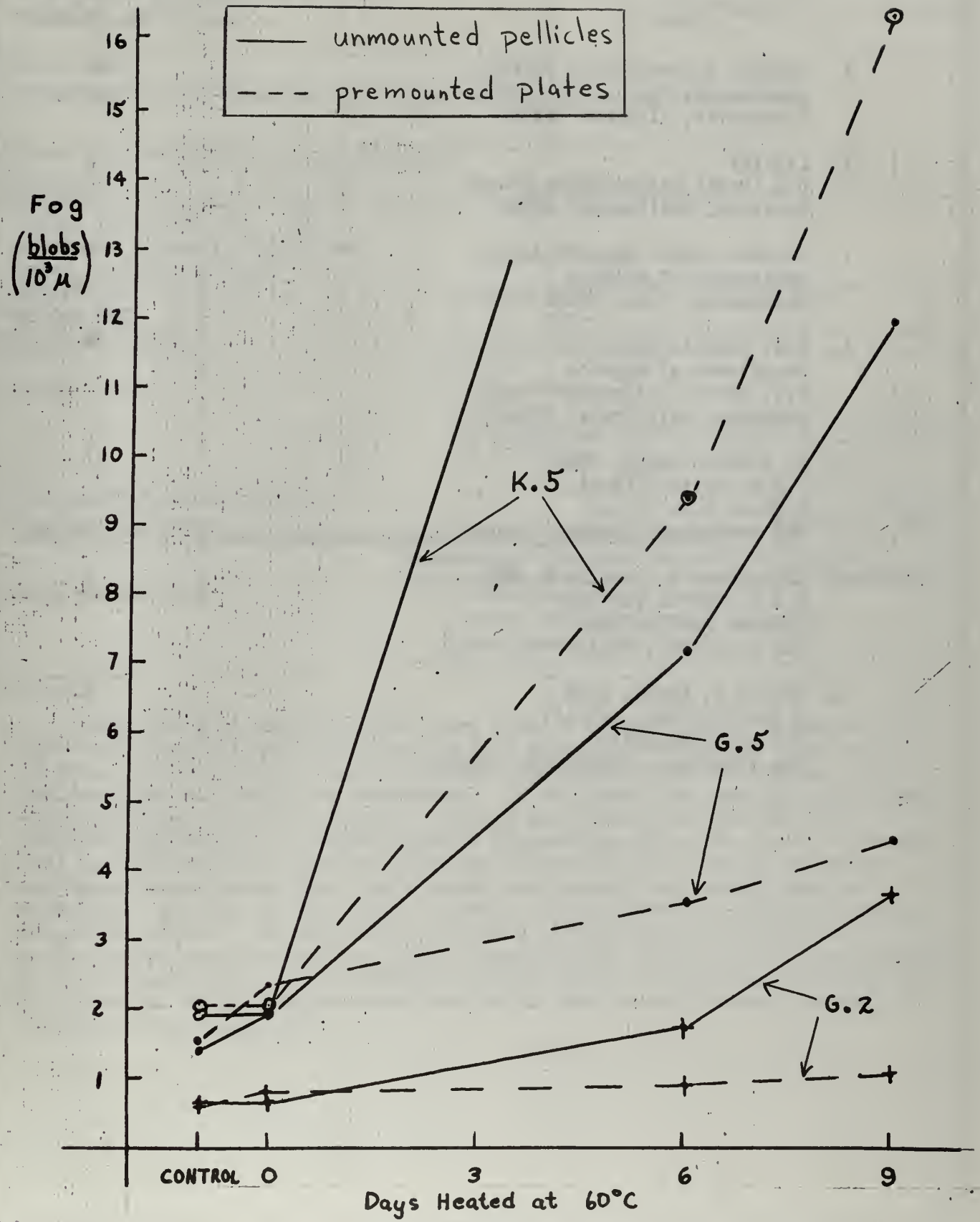

FIG. 21. Fog Density in Plates and Pellicles

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The effects of heating Ilford types G and K emulsion prior to exposure or processing have been studied. Samples were heated at 55-60°C for times up to 16 days, and other samples were assembled into stacks in which a temperature gradient (-20°to +100°C) was maintained. It was found that sensitivity to fast electron tracks can be increased by heating and drying, but that for each emulsion type there is a rather critical temperature above the growth of random "fog grain" background soon makes the emulsion useless. Attempts to remove the latent image showed that track images are removed more easily than the background, so that the usefulness of emulsions that have been heated too much cannot be regained. We noted an interesting difference in the behavior of pellicles and pre-mounted plates which suggests that the plates are less affected by high temperatures. Measurements of Brinell hardness and thermal conductivity as a function of the humidity are reported, as are several comments on the handling of dry emulsions.

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